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UNITED STATES AIR FORCE RESEARCH LABORATORY

INTEGRATION OF A LEGACY SYSTEM WITH NIGHT VISION TRAINING SYSTEM (NVTS)

Gretchen M. Anderson

L-3 Communications, Link Simulation and Training
6030 South Kent Street
Mesa AZ 85212-6061

Craig A. Vrana

Lockheed-Martin
6030 South Kent Street
Mesa AZ 85212-6061

Joseph T. Riegler

The Boeing Company
6030 South Kent Street
Mesa AZ 85212-6061

Elizabeth L. Martin

Air Force Research Laboratory
Warfighter Training Research Division
6030 South Kent Street
Mesa AZ 85212-6061

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AIR FORCE MATERIEL COMMAND
AIR FORCE RESEARCH LABORATORY
Human Effectiveness Directorate
Warfighter Training Research Division
6030 South Kent Street
Mesa AZ 85212-6061

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6. AUTHOR(S)
Anderson, Gretchen M. ; Author
Vrana, Craig A. ; Author
Riegler, Joseph T. ; Author
Martin, Elizabeth L. ; Author

7. PERFORMING ORGANIZATION NAME AND ADDRESS
L3 Communications
Link Simulation and Training
6030 South Kent Street
Mesa, AZ85212-6061

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Warfighter Training Research Division
6030 South Kent Street
Mesa, AZ85212-6061

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19. NAME OF RESPONSIBLE PERSON
Casey, Liz
liz.casey@williams.af.mil

19b. TELEPHONE NUMBER
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Area Code Telephone Number
480988-6561
DSN
474-6188

NOTICES

ELIZABETH L. MARTIN
Project Scientist

DEE H. ANDREWS
Technical Advisor

CURTIS J. PAPKE, Colonel, USAF
Chief, Warfighter Training Research Division

Copies of this report may be requested from:

Defense Technical Information Center
8725 John J. Kingman Road, Suite 0944
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Gretchen M. Anderson [1]
Craig A. Vrana [2]
Joseph T. Riegler[3]
Elizabeth L. Martin[4]

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

L-3 Comm, Link Simulation and Training[1]
Lockheed Martin[2]
And The Boeing Company[3]
6030 South Kent Street
Mesa AZ 85212-6061

Air Force Research Laboratory
Warfighter Training Research Division[4]
6030 South Kent Street
Mesa AZ 85212-6061

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Human Effectiveness Directorate
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PREFACE

This research was conducted under for the Air Force Research Laboratory, Human Effectiveness Directorate, Warfighter Training Research Division (AFRL/HEA) under USAF Contract No. F41624-97-C-5000, and Work Unit 4924-B3-01, Night Vision Device Training Research and Development. The Laboratory Contract Monitor was Dr Elizabeth L. Martin, AFRL/HEA.

EXECUTIVE SUMMARY

The increase in tactical night operations has resulted in the requirement for improved night vision goggle (NVG) training and simulation. The Night Vision Training System (NVTS), developed at the Air Force Research Laboratory's Warfighter Training Research Division (AFRL/HEA), provides high-fidelity NVG imagery required to support effective NVG training and mission rehearsal. Acquisition of a multichannel NVTS, to drive both an out-the-window (OTW) view and a helmet-mounted display (HMD), may exceed the resources of some training units. An alternative could be to add one channel of NVG imagery to the existing OTW imagery provided by the "legacy" system.

This evaluation addressed engineering and training issues associated with integrating a single NVTS HMD channel with an existing legacy system. The engineering analysis examined database correlation, latency differences, and host-to-NVTS communications. The simulator flight evaluation assessed the training implications of operating with the disparities between two databases.

The simulator scenario used in this evaluation allowed the pilots to observe potentially distracting disparities and was not representative of any specific training task. The scenario consisted of a route with changing altitudes and headings in the area around Tonopah. The evaluation was conducted in a high-fidelity F-16 Block 30 simulator located in the AFRL/HEA Distributed Mission Training (DMT) testbed at Mesa AZ.

Four NVG-experienced pilots flew the test route at two illumination levels in two simulator configurations. A single image generator (IG) generated imagery for both the HMD and OTW scenes in one configuration, while the second configuration employed separate IGs to drive imagery for each scene. Pilots rated the degree of disparity they noticed between the HMD and OTW scenes for various scene attributes and the effect on flight performance. The findings demonstrated the potential for integration of an NVTS channel with an existing legacy system. Latency and terrain elevation differences between the two databases were measured but did not significantly impact system integration or pilot ratings. When integrating other legacy systems with NVTS, disparities may exist between the two databases. In these cases, the best alternative is to modify the OTW database to correlate with the NVTS database. Pilot ratings and comments indicate (a) display brightness and contrast levels of the OTW scene should be set to correspond to real-world, unaided luminance values for a given illumination condition; (b) disparity in moon phase and position between the two sky models should be minimized; and (c) star quantity and brightness in the OTW scene and the NVG scene, as rendered on the HMD, should be as consistent with real-world conditions as possible.

INTEGRATION OF A LEGACY SYSTEM WITH NIGHT VISION TRAINING SYSTEM

INTRODUCTION

Within the last decade, the use of night vision goggles (NVGs) has expanded to many military and law enforcement aviation platforms. This escalation in NVG operations has dictated substantial improvements in training syllabi, to include addition of NVG training in the simulator. Advancements in image generation technology and physics-based simulation have made it possible to effectively simulate the NVG response at the computational dynamic range of a computer. The "simulate" approach allows for greater realism with regard to NVG effects such as capturing the dynamic range of the night sky and NVG special effects of halos, gain, and noise. The Night Vision Training System (NVTS) is an architecture of software and hardware components for a physics-based NVG simulation developed at the Air Force Research Laboratory, Human Effectiveness Directorate, Warfighter Training Research Division (AFRL/HEA), Mesa, AZ. This prototype system was developed to display simulated NVG imagery in a helmet-mounted display (HMD) via one or two image generator (IG) channels while employing the other channels of the same IG to display the "unaided" night scene.

Acquisition of the prototype system with a multichanneled IG may exceed the resources of some NVG training units. An alternative approach may be to integrate a single NVTS channel with an existing legacy training simulator. This approach allows users to train in a realistic, effective NVG simulation environment without incurring the cost of a completely new training system.

This research effort addresses the engineering and training implications associated with integrating NVTS into a legacy system. While the legacy approach may be more cost effective than the acquisition of an entirely new visual system, integrating NVTS with an existing legacy system may have unexpected engineering and training effectiveness pitfalls. These potential drawbacks should be explored before deciding on this approach to fulfill the NVG training requirement. We conducted this evaluation to address the engineering and training issues involved with integrating a channel of simulated NVTS imagery, generated by one IG, with out-the-window (OTW), unaided night imagery as generated by a separate legacy IG. Findings of this engineering and training evaluation will result in recommendations for follow-on specifications for NVTS integration in fielded legacy systems.

The primary training concern is the extent of negative impact on training value due to differences between two IGs (e.g., database mismatches). The primary engineering issues concern the feasibility of integrating two different visual systems into one training system. Fundamental integration issues include database and temporal correlation between two very different hardware architectures. Databases can be forced to correlate but the time required for different IGs to generate a frame of video is often fixed by the hardware designers and the runtime programmers.

No integration will ever truly be seamless, so decisions must be made as to what is acceptable from implementation cost and training value perspectives. Since all simulation systems are not the same, the findings of the present analysis may not apply equally to all systems under consideration. Conceptually, the systems used here must be viewed as "nominal" representatives of the class of training systems that exist in the operational world. An attempt has been made to keep the evaluation generic, but it is inevitable that the specifics of any given system will influence the findings. We attempted to identify the issues that may be applicable to other simulation systems.

APPROACH

Test Platform

NVTS was implemented in a stand-alone configuration to address issues of integration to legacy training systems. All work was done leveraging existing AFRL/HEA equipment (cockpits, displays, IGs, and databases) as test cases for generic legacy integration.

Legacy system

AFRL/HEA in Mesa, AZ is researching technologies and training applications in a Distributed Mission Training (DMT) testbed comprised of four F-16 Block 30 simulators. The basic components of a single-ship system within DMT include an F-16 multi-task trainer (MTT) cockpit, a rear-projection display system, SE 2000+ IG, and a detailed photo-realistic terrain database. The legacy system components (depicted in Figure 1) are described in more detail in the following section of this report.

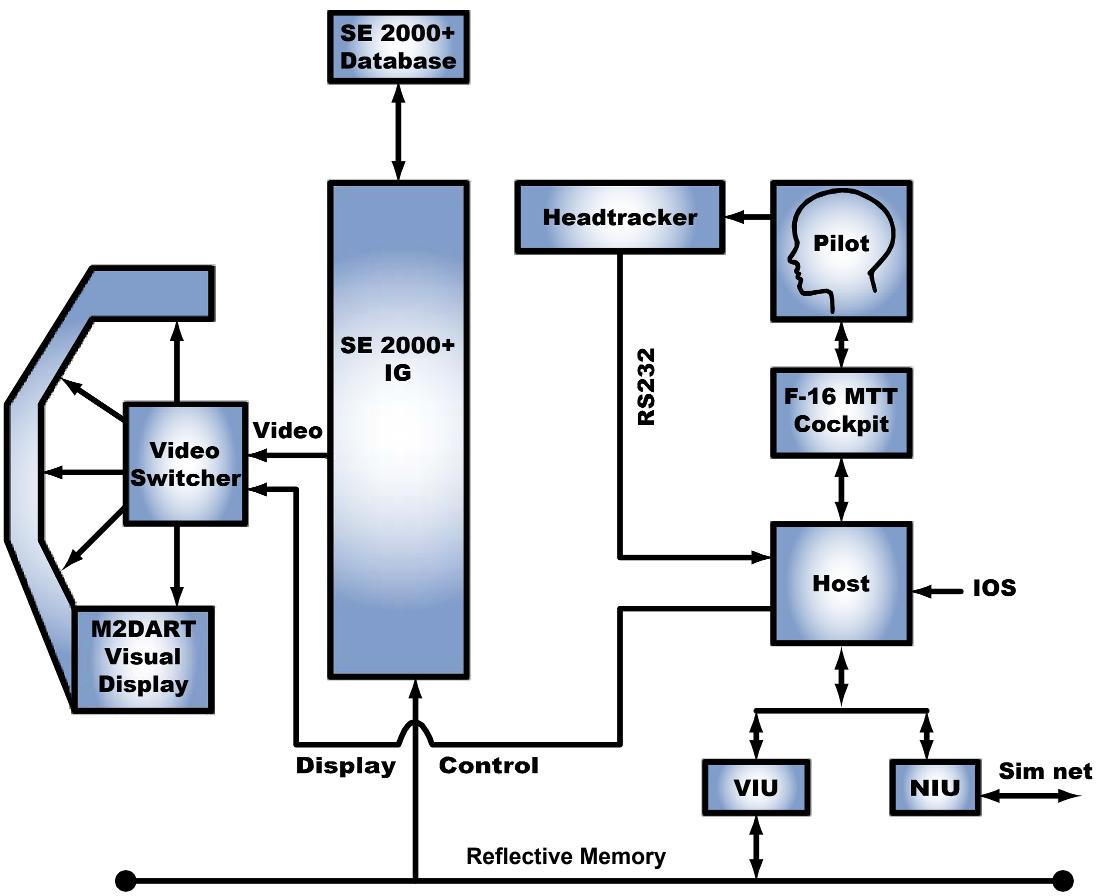

Figure 1. Single-ship DMT testbed configuration with SE 2000+ IG

F-16 MTT

An F-16 MTT has the capability to train operational aircrews in a variety of skills. The F-16 MTT uses existing Air Force-owned operational flight trainer (OFT) computer code along with aircraft operational flight program (OFP) software from the aircraft systems' line replaceable units (LRU) provided by the aircraft logistics depot. OFT and LRU software were converted to run at the same

50 Hz rate of the aircraft microprocessors. The F-16 MTT cockpit is functionally equivalent to its respective aircraft. It has full-fidelity instrumentation and controls. “Host” refers to the software and computer portion of the MTT system.

<u>M2DART Visual Display</u>

The Mobile Modular Display for Advanced Research and Training (M2DART) is a rear-screen, real-image, display system that uses commercial off-the-shelf (COTS), cathode-ray tube (CRT) projectors to provide OTW visual imagery to the user with a full 360° field of regard. The M2DART (Figure 2) has eight flat projection screens linked together to display eight channels of full-color imagery. The projectors can be controlled via an infrared remote control and a laptop computer for ease of maintenance. The display surfaces are diffuse screens, made of a 3/8" thick acrylic substrate. Lightweight mirrors are used to make the system more compact. The mirrors are fabricated from Mylar film stretched around aluminum frames with a Styrofoam core. The screen frame support structure is designed such that the front and two side windows can be easily modified to accommodate any fighter-sized cockpit while the two rear screens, mounted on hinged frames, allow ingress/egress to the system. Due to the relatively small surface area on these screens in comparison to large dome displays, the imagery is significantly brighter with higher contrast.

Figure 2. M2DART Visual Display

<u>Image Generator</u>

The COMPUSCENE SE 2000+ IG is a modular, real-time image generation system for simulators. The IG outputs six analog video channels consisting of full-color, raster scan video in a 2:1 interlaced or noninterlaced format at a field rate of 60 Hz. The raster line resolution is programmable over a wide range of display formats ranging from 525 to 1023 lines per frame. The video is supplied as separate color signals for red, green, and blue (RGB) and composite sync for each display channel. For this effort the SE 2000+ was set to a resolution of 1280 pixels x 1023 lines, interlaced format. SE 2000+ sun vector controls were manipulated to achieve the desired levels of sky and terrain illumination.

Database

The database used for this evaluation depicted the Nellis AFB, NV range complex (See Figure 3). This database consists of 20, 1° x 1°, geographical cells (or geo-cells; approximately 60 nm x 60 nm each), and was generated as a blended, two level-of-detail (LOD) database. Terrain was created using Digital Terrain Elevation Data (DTED) and geotypical culture on the database was created using Digital Feature Analysis Data (DFAD). Geographic texture applied to the terrain was created using the National Imagery and Mapping Agency's (NIMA) Controlled Image Base (CIB) data. A 1° x 1° texture map was created from NIMA data with an approximate resolution of 4000 x 4000 pixels. These texture maps were re-sized to 256 x 256 pixels using Adobe Photoshop™. The pixel maps were applied to the database such that one 256 x 256 pixel map covered a single geo-cell. Approximate polygon count in the first LOD (highest level of detail) is 48,600 polygons per geo-cell, while approximately 28,100 polygons per geo-cell are in the second LOD.

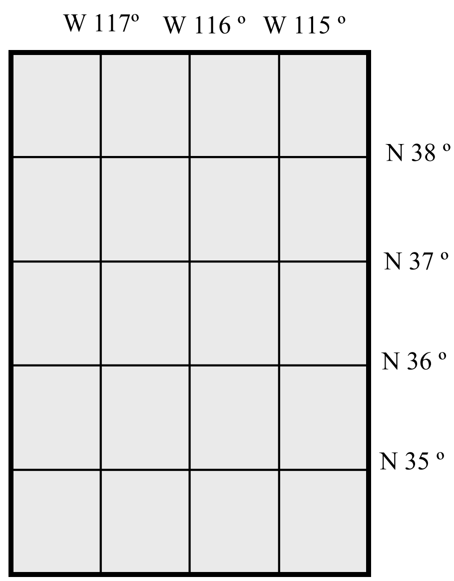

Figure 3. Lat/Long coordinates of Nellis range complex database

Night Vision Training System (NVTS)

NVTS is an NVG sensor simulation using a physics-based approach to provide an accurate in-band, radiometric response for reflectance and aspect of the material-coded texel under illumination. As the illumination level and angle change in the simulation, the amount of light reflected from each texel to the viewpoint changes. An NVTS-simulated NVG image of the Nellis range complex is displayed in Figure 4.

NVTS employs a modular architecture, which consists of the following major components: an IG, a photorealistic OTW database, a material-coded sensor database, runtime software, an HMD, a head tracker, AFRL's SensorHost software running on a PC-caliber computer and AFRL's Video Processor for Real-time Simulation (ViPRS). Figure 5 shows the NVTS architecture as installed at AFRL/HEA.

Figure 4. Simulated NVG image

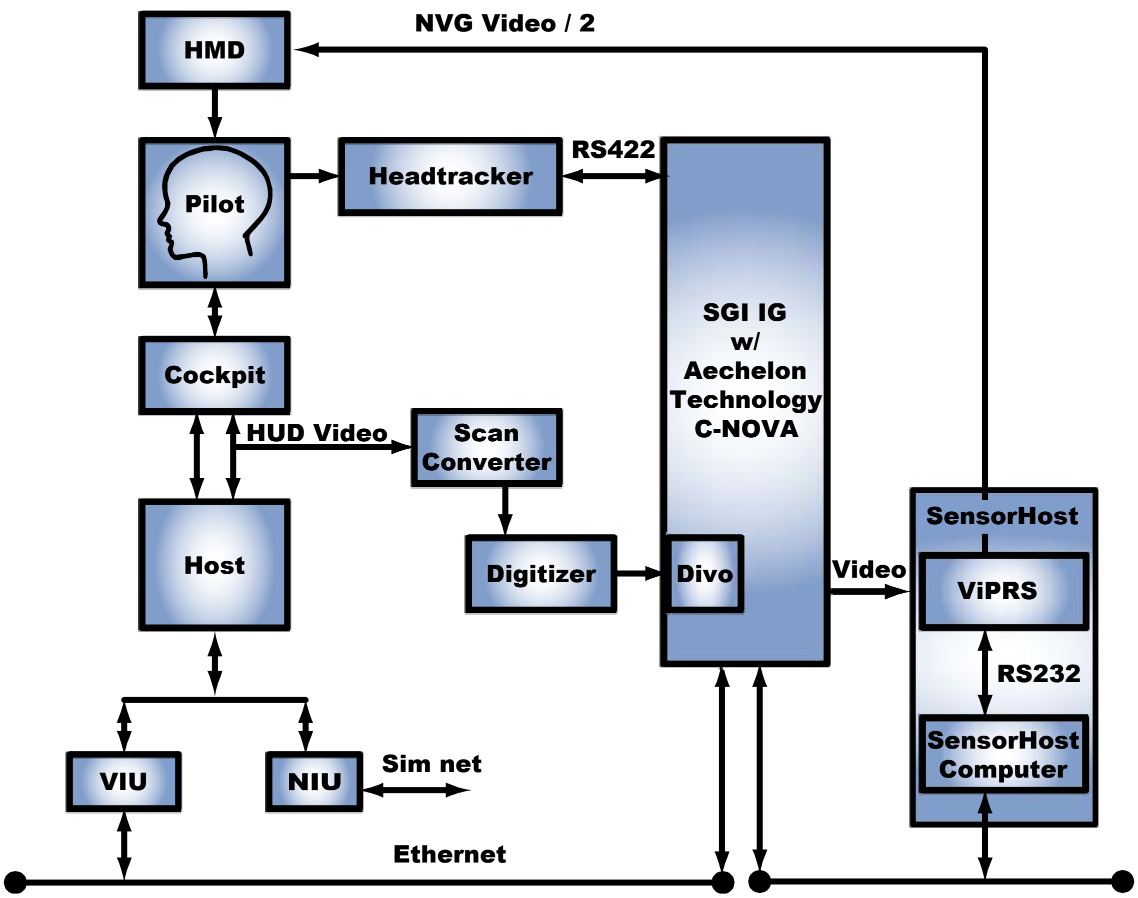

Figure 5. NVTS DMT testbed architecture

Image Generator

An SGI™ Onyx2® IG rendered the NVTS imagery for this evaluation and drove coincident OTW rear-screen projected display channels during one condition. The IG consisted of 16 64-bit MIPS R10000 processors running at 250 MHz, 3 GB of system memory, over 500 GB of hard drive space in a RAID 5 (Redundant Array of Inexpensive Discs 5) configuration, a digital video option (DIVO) board, and six InfiniteReality3 (IR3) graphics pipelines.

The Onyx2 system contains high-speed, bidirectional interconnects for moving data from one part of the system to another. These interconnects operate at 1.6 GB per second, full duplex, or 800 MB per second in each direction. This high bandwidth capability is essential to performing the massive amounts of lighting and texturing calculations required for real-time sensor simulation. Each of the Onyx2's IR3 graphics pipelines consist of two Geometry Engine® processors, four 256 MB Raster Managers®, and a dual-channel, programmable Display Generator® board. The Geometry Engine processors perform lighting calculations and geometric transformations such as translation, rotation, and scaling. Geometry Engine processors also execute image-processing functions such as convolution and histogram equalization, more effectively than central processing units (CPUs). Raster Managers scan-convert data from Geometry Engine processors into digital images. Raster Managers also perform pixel operations, including z-buffer testing, color, and transparency blending, texture mapping, and multi-sample anti-aliasing at real-time rates. The Display Generator converts digital data from the Raster Managers into analog video signals for display. A dual-channel Display Generator provides one high-resolution analog output and a second high-resolution analog or NTSC/PAL output. The outputs of the Display Generator are programmable to any resolution that does not exceed the total output bandwidth of the system.

NVTS Databases

The correlated, geospecific, photorealistic OTW and material-coded sensor databases cover 380 nautical miles by 420 nautical miles of the Nellis range complex. These databases were derived from multispectral satellite imagery, aerial photography, material spectral response data, and DTED. The databases include insets with submeter resolution imagery and full three-dimensional cultural feature extraction. Using multiple offline processes, the textures used for the NVG visual are given a per-texel, multilayer material classification, a normalized directional vector, and a color. Then discreet lighting and environmental conditions are processed to include effects in the database that cannot yet be rendered in real time, like self-shadowing terrain and shadows from clouds.

Runtime Software

Aechelon Technology's C-NOVA runtime software was used for this project. The Aechelon Technology runtime software transforms an SGI graphics computer into a more traditional IG. This software interfaces to the host via the Visual Interface Unit (VIU). The host tells the IG what to draw on the displays according to symbols and flags described in the Interface Control Document (ICD) through the VIU. The ICD describes everything that the host will be able to control on the IG. The Aechelon Technology software displays a variety of effects (e.g., horizon glow, lightning flashes) according to input from the host. The software loads the photorealistic texture for OTW simulation of the Nellis range complex, which is then displayed as it would appear at night (unaided) under the selected illumination conditions.

Sensor simulation is produced by the runtime software, which loads the material-coded texture of the same area as specified by the host's coordinates. The runtime software then renders the sensor displays according to the environment specified by the host, the instructor-operator station, and the SensorHost computer. The NVG display is rendered on three separate color channels according to the type of object to be rendered. The red channel displays emissive types of objects such as fires, lights, the moon, and stars. The green channel displays reflective objects like the

terrain, targets, and the ownship mask which represents the user's local surroundings in the NVG view. (The NVTS prototype system includes a material-coded geometrical model of the interior and exterior features of an AV-8B.) The blue channel displays other objects that would cause the system performance to degrade if they were rendered to another color. Noise and the Heads Up Display (HUD) are examples of objects rendered to the blue channel. The brightness of each texel rendered in the NVG display is the culmination of the position and amount of scene illumination, the directional normal, and the response of the material returned by SensorHost.

NVTS HMD

The Datavisor® NVG HMD, manufactured by n-vision™, presented the simulation to the NVTS user during this evaluation. The basis of the HMD is an actual ITT F4949 NVG shell. It attaches to standard Aviator's Night Vision Imaging System (ANVIS) mounts as shown in Figure 6. This allows a pilot to train more comfortably, with his/her own equipment. The HMD incorporates miniature CRTs mounted inside the NVG shell in place of the intensifier tubes and the objective lenses. The CRTs are coated with P-43 phosphor; the same phosphor used in current NVGs, to provide the same color and decay characteristics. Display resolution of the HMDs is from 1024 lines to 1350 lines, noninterlaced, refreshed at 60 Hz. We used a resolution of 1024 lines for this evaluation. These HMDs provide the same form, fit, function, weight, and center of gravity of actual NVGs, to produce a more realistic simulation.

Figure 6. NVTS Helmet-Mounted Display (photograph courtesy of n-vision™)

Head Tracker

The NVTS currently uses a magnetic head-tracker to slave the NVG image to the pilot's helmet position while maintaining minimal latency. The Polhemus™ Fastrak® head-tracking system was used for purposes of this research. Fastrak uses electromagnetic fields to determine position and orientation of a remote object. The technology is based on generating near field, low frequency, magnetic field vectors from a single assembly of three collocated, stationary antennas (transmitter), and detecting the field vectors with a single assembly of three collocated remote sensing antennas (receiver). The sensed signals are input to a mathematical algorithm that computes the receiver's position and orientation, relative to the transmitter. Fastrak consists of a System Electronics Unit (SEU), one to four receivers, a single transmitter, and a power supply. A single receiver may be operated at an update rate of 120 Hz. Fastrak's static accuracy is 0.03 in. (0.08 cm) RMS for the X, Y, or Z receiver position, and 0.15° RMS for receiver orientation. Fastrak provides the specified accuracy when the all-attitude receivers are located within 30" (76 cm) of the transmitter. Operation with separations up to 120 in. (305 cm) is possible with reduced accuracy. The instrument's resolution is 0.0002 in. of range (0.0005 cm of range), and

.025°. Latency of the system is 4.0 ms from center of receiver measurement period to beginning of transfer from output port ("3 Space User's Manual," Polhemus Inc., VT, 1993). The receiver is secured to the pilot's helmet with an easily removable Velcro tag.

<u>SensorHost and the Video Processor for Real-time Simulation</u>
SensorHost is an Intel-based, Linux host that performs all physics and NVG-specific computations for the NVTS NVG simulation. The SensorHost system maintains frame-by-frame communication over an Ethernet connection with the runtime software on the IG, as prescribed by the SensorHost ICD. The ViPRS is a video post-processing system that is connected between the IG and the HMD. The ViPRS captures the mean pixel value of each color channel from the IG's analog video output at the target screen resolution and frame rate. The ViPRS applies a gain and injecting noise into the IG video as specified by the SensorHost. All data including video mean and parameters for gain and noise injections flow between the video processing system and the SensorHost via an RS-232 link.

The NVTS constructs a 24-bit RGB color word to contain radiance information to keep more levels of radiance in the scene. Each byte of the RGB color or each texel is used as a byte in the word that comprises the total luminance. Thus, each of the RGB digital-to-analog converters (DACs) carries a portion of the total 24-bit luminance word downstream into the ViPRS in an analog sample. The ViPRS reconstitutes the 24-bit data word from the IG RGB analog outputs and then drives the HMD. By aggregating the RGB bytes in this manner, the dynamic range actually driving the display device is sufficient to treat the orders of magnitude of radiance perceived across the night scene.

<u>NVTS / SE 2000+ Integration</u>

Integration Process

This evaluation addressed integration of a legacy training system with an NVTS channel. The SE 2000+ was chosen to drive the OTW channels while the SGI drove the NVTS channel. Figure 7 illustrates the legacy system as integrated with the NVTS. The NVTS components are shown within the gray dashed outline.

The steps involved with integrating NVTS to the legacy F-16 trainer were as follows:

1. Provided video cables for the HMD from the ViPRS.
2. Provided a serial cable for the head tracker from the SGI IG.
3. Provided an Ethernet cable for the host to NVTS IG network connection.
4. Ensured network communication was viable.
5. Provided a head tracker at the cockpit.
6. Provided an HMD at the cockpit.
7. Provided RS-170 video of the HUD display by scan conversion.
8. Provided a cable from the RS-170 version of the HUD to the digitizer.
9. Provided software to translate between the IG ICD and the host ICD.
10. Modified host software to multicast to a set of IP addresses instead of only sending to a single IP address.
11. Added capabilities to the host needed for night operations (e.g., light switch position, afterburner on / off).
12. Modified databases to correlate with each other for night operations (e.g., important lights, targets, airfields, etc. need to be in the same locations and elevations).

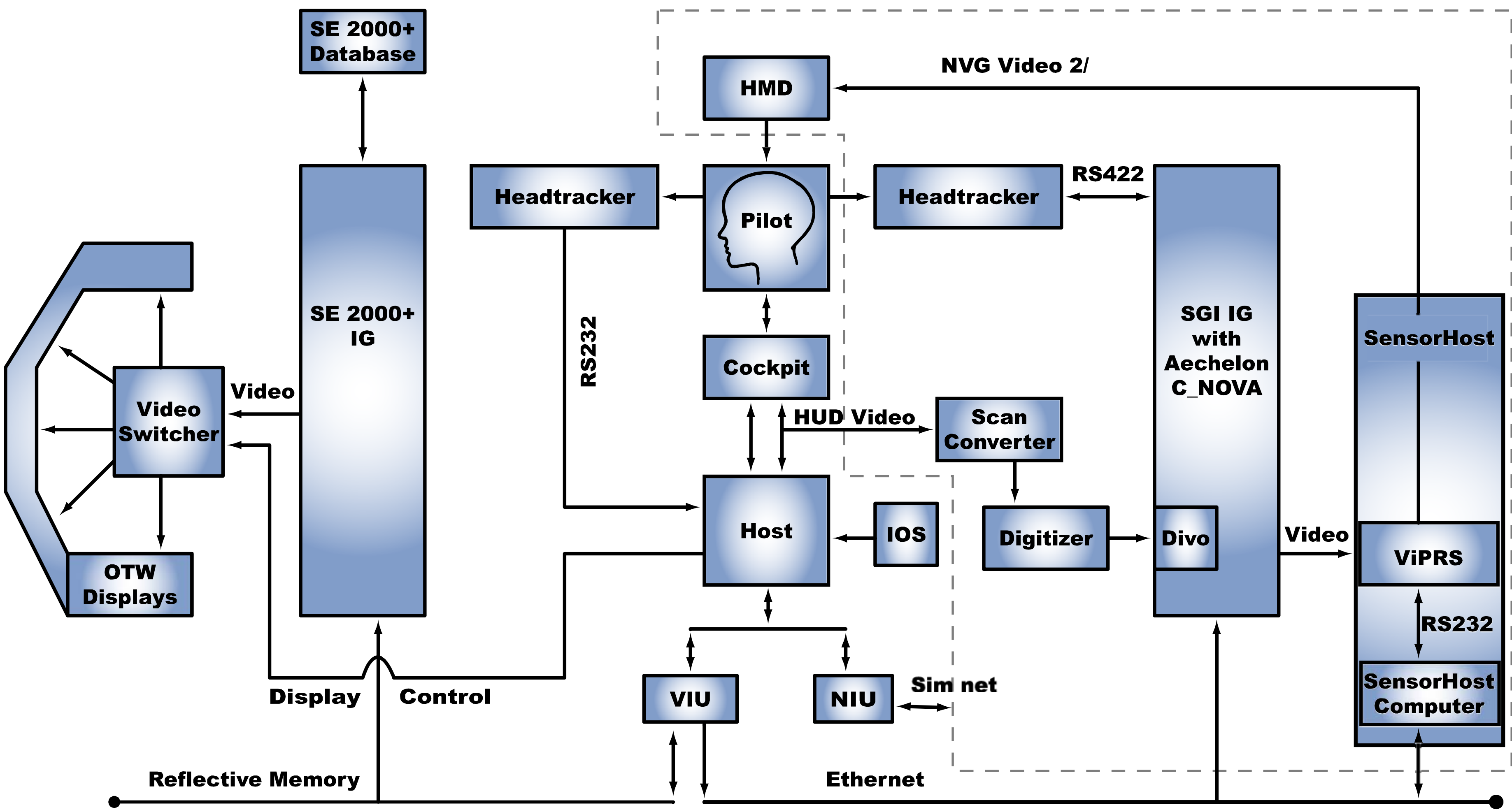

Figure 7. Legacy system integrated with NVTS

IG Integration Assessments

Differences in terrain elevation and system latency between the two IGs were key issues examined prior to integrating this evaluation system.

Terrain Elevation Correlation
Any two databases generated with different tools have dissimilar terrain elevations at many points. These inconsistencies cause ground forces to appear at different elevations between simulations. For example, during a multiplayer exercise one player may see a particular tank correctly placed on the ground while a second player operating with a different database may not see the tank because it is underground. At the same time a third player, operating with yet another database, may see the same target floating in the air even though the target is at the same location and elevation in each instance.

Database variations may be due to the fact that database generation systems use different algorithms to convert terrain elevation into polygons. Also different levels and versions of DTED may be used to construct the databases. The variations between the databases in the AFRL/HEA networked "synthetic battlespace" required important features (i.e., runways, targets, etc.) to be forced to the same latitudes, longitudes, and elevations for the SGI and SE 2000+ databases. Surrounding areas were blended into the original terrain skins of the databases.

Terrain elevations were compared for a set of 27, 063 locations (sampled at 2,000 ft intervals) within one geo-cell of the SE 2000+ and SGI databases. The frequency distribution of the absolute differences in terrain elevation between databases is plotted in Figure 8.

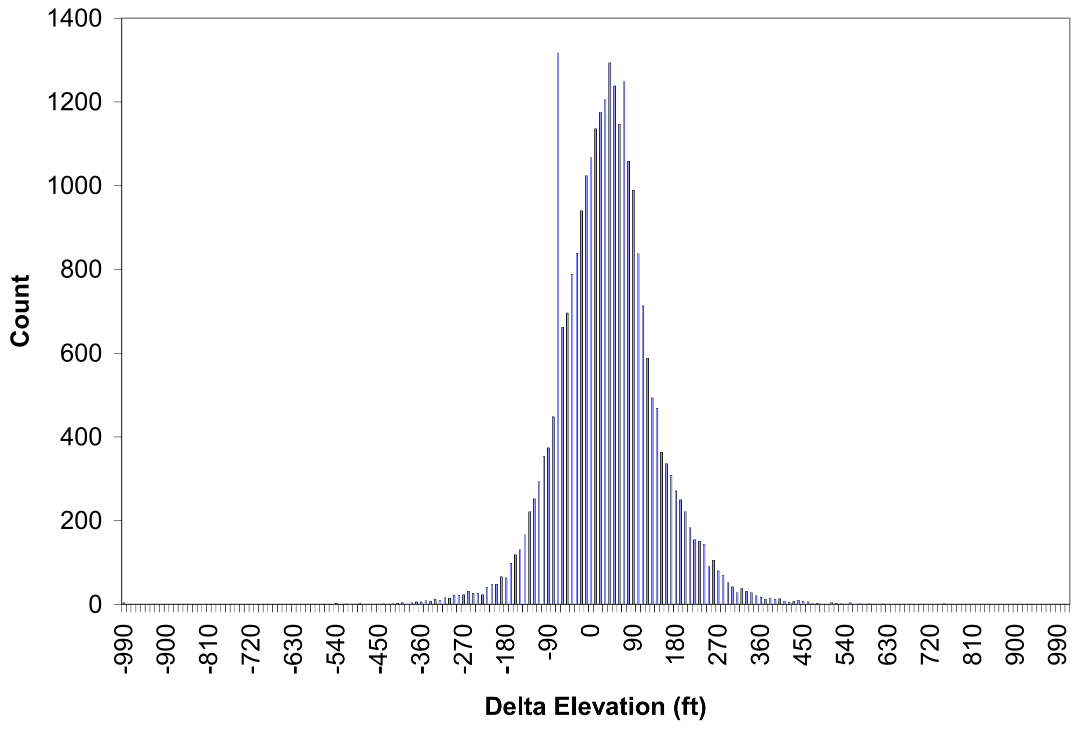

Figure 8. Frequency distribution of terrain elevation differences between SE 2000+ and SGI databases

The percentages of measurements obtained for a range of elevation differences are provided in Table 1. The majority (73%) of corresponding measurements between the two databases varied by 100 feet or less (mean difference = 81.0 ft, standard deviation = 73.2 ft). The elevation differences of nearly all corresponding points were within 500 feet of each other.

Table 1. Summary of terrain elevation differences between SE 2000+ and SGI IG databases

Absolute Difference in Terrain Elevation (ft)	Percent of Total Measurements
0	3.9
$\leq$ 10	11.9
$\leq$ 50	42.1
$\leq$ 100	73.3
$\leq$ 150	86.9
$\leq$ 200	93.5
$\leq$ 500	99.8

Since the two databases did not correlate exactly, one IG had to be selected to provide Height Above Terrain (HAT) and other database specific information back to the host (e.g., The radar altimeter would be constantly jumping if both IGs were providing HAT information from their respective databases.). The IG selection should be based on the purpose of the training. For example, the OTW IG should provide information to the host if the main task involves runway approaches where the primary visual input to the pilot is provided by the OTW (unaided) database because pilots do not normally wear NVGs while landing. If the simulator mission involves ordnance delivery or low-level flying (when NVGs are essential), the system should be configured such that the host takes information from the NVG HMD IG. There may even be situations where switching from one IG to the other may be necessary and is quite possible, but only one IG at a time should provide information to the host. Since the flying scenario used for this evaluation did not involve ordnance delivery, approaches, or low-level flight, either IG could have been used to provide information to the host. The OTW IG was selected for this purpose due to ease of integration in this instance.

<u>Latency Evaluation</u>

As part of a separate evaluation effort, AFRL/HEA personnel conducted tests to determine the latency of the Lockheed Martin SE 2000+ and the Aechelon Technology C-NOVA/SGI IGs. Results of this latency testing demonstrated that the SE 2000+ has a consistent latency value because it is synchronized with the cockpit. The C-NOVA/SGI IG is not synchronized with the cockpit, and consequently, has a ramping effect of one frame (16.7 ms). This results in a range of latency values for the C-NOVA/SGI IG. Latency test results are summarized in Table 2. The values provided in Table 2 represent (a) the latency from cockpit input to start of the first video field and (b) latency from cockpit input to end of fully completed video frame (All lines in the display changed.). Note that latency produced by the addition of a head tracker was not accounted for during this test.

Table 2. Latency values for SE 2000+ and SGI IGs

Image Generator	Latency to start of the first video field (ms)	Latency to end of fully completed video frame (All lines in the display changed) (ms)
SE 2000+	59	92
C-NOVA/SGI	51 – 68+	68 – 85+

Subjective Flight Evaluation

The purpose of the subjective flight evaluation was to determine the training implications associated with integrating NVTS with a legacy system. Two separate configurations of the DMT testbed were required to support this evaluation. One condition consisted of SGI imagery in both the OTW and NVTS HMD scenes as depicted in Figure 5. The second condition consisted of SE 2000+ database imagery in the OTW scene (legacy components) with NVG imagery in the NVTS HMD SGI as shown in Figure 7. Four NVG-experienced pilots flew a prebriefed route in each configuration at two illumination conditions. Pilots then rated the degree of mismatch they noticed between the NVTS HMD and OTW scenes for a set of scene attributes. Pilots also rated the extent to which any mismatches affected flight performance.

Out-the-Window Display Configuration

Database Modifications
A section of the Nellis range complex (depicted in Figure 9) was selected for use in this evaluation. This area was material-coded for NVTS and consisted of high-resolution (5 m) imagery. A route of flight, beginning and ending just west of the Tonopah runway, was planned within this area. The scene content of the SGI visual database (used in the NVTS HMD and OTW scenes) area of interest consisted of the Tonopah runway lights and buildings, surrounding cultural lights, and mountains. Initially the SE 2000+ database did not contain any cultural lighting or runway lights in this area of interest. A preliminary assessment of the SGI and SE 2000+ simulations indicated that the obvious disparities between the two databases, with respect to ground lights and terrain/sky luminance, would have implications for NVTS performance / training. Therefore, the SE 2000+ database was modified to include Tonopah runway lights and several groupings of ground lights that corresponded to the lights in the SGI database viewable along the route of flight.

The five groups of lights added to the SE 2000+ database consisted of:

1) A grouping of five lights 16.5 mi east of Tonopah, west of Cedar Pass
2) A sub-group of three lights at N37°42.6’ W116°26.8’
3) A sub-group of two outlying lights at N37°41.7’ W116°24.7’ and N37°43.3’ W116°26.2’
4) A grouping of three lights off the end of Tonopah at N37°39.3’ W116°39.3’, N37°38.4’ W116°39.2’, and N37°38.6’ W116°38.9’
5) A grouping of five lights, 5.5 mi north of Tonopah runway (4 white, 1 red) at N37°53.0’ W116°45.8’.

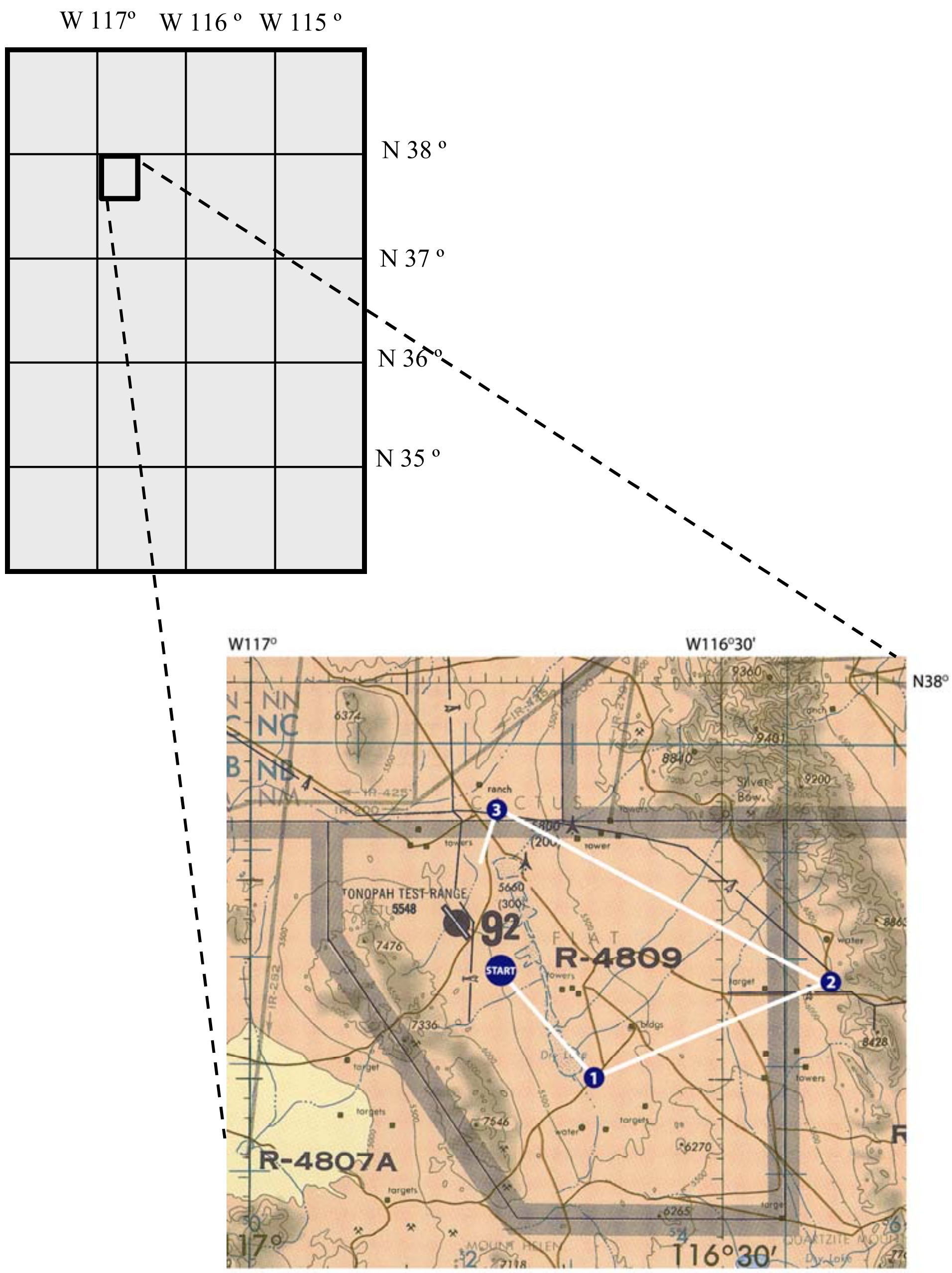

Figure 9. Topographic depiction of route of flight area within Nellis range complex database

<u>Display Brightness and Contrast Settings</u>

Screen settings for brightness and contrast were manipulated to approximate OTW luminance levels for the simulated dirt, sand, dry lakebed, and sky found in our test area of the SGI and the SE 2000+ databases. Existing real-world luminance data for the materials of interest were compared with the same type materials in the OTW scene for each projector. The OTW scene was frozen so all four of the OTW simulated materials were visible on one screen. Then recorded luminance measurements were recorded for each material using a Minolta LS-100 hand-held photometer with a 1° measuring field. Prior to this evaluation, this same instrument was used to obtain real-world material luminance readings. “Luminance” refers to the luminous intensity or brightness of a surface. Manipulating the brightness setting on a projector will change the

luminance of the materials on that display accordingly. The brightness levels were then adjusted until the luminance readings for each of the simulated materials in the scene approximated the luminance levels of the real-world data for selected illumination levels (clear starlight and quarter moon). Then the contrast was adjusted subjectively and a final reading was taken to ensure the luminance levels were correct.

This process was repeated for each of the four screens. Luminance measurements for each material were taken at two or three points within a section of the material (e.g., center and edge of the dry lakebed). The measurements were repeated for those same simulated materials while they appeared in the center of each screen, and then near an edge of each screen. The various materials, placement on the screen (center and edge), moon illumination level, and input from subject-matter experts were all considered while determining screen brightness and contrast levels. The software in the SE 2000+ permitted screen settings for ground and sky to be adjusted independently. The SGI did not have the capability to allow for separate sky and terrain luminance settings at the time of this evaluation.

Participants

Four NVG-experienced pilots, ranging in age from 32 to 41, participated in the flight evaluation. The pilots had between 1,000 and 5,000 total flight hours, with NVG flight hours ranging from 100 to 850 hours. Two pilots had 100 and 300 NVG hours in the F-16. One pilot had 700 hours of NVG flight experience in the MH-53. The fourth pilot had 850 combined hours of NVG experience in the Casa 212 and UH-1.

Simulator Flight Test Conditions

Test conditions examined in this effort are presented in Table 3. Illumination levels were: (a) clear starlight and (b) quarter moon (equivalent to 50% moon disc) and selected to assess the degree of mismatch between the NVTS HMD and OTW scenes at different levels of illumination.

Table 3. Test conditions for present evaluation

Test Condition	Illumination Level	Simulator Configuration
1	Clear Starlight	NVTS + SGI
2	Clear Starlight	NVTS + SE 2000+
3	50% Moon Disc	NVTS + SGI
4	50% Moon Disc	NVTS + SE 2000+

Procedure

Each pilot flew a daytime familiarization in one of the F-16 MTTs for 15 minutes. The pilots then flew the route of flight (depicted in Figure 10) for each of the four test conditions during a single session. Two pilots started the session with the SGI OTW configuration, and two began the session with the SE 2000+ OTW. Pilots completed the route for both illumination conditions within the initial OTW IG configuration before proceeding to the second OTW IG condition.

The route began just west of the Tonopah runway at 11,000’ MSL (6000’ AGL), and continued south to the Steerpoint 1, descending to 8,000’ MSL. The pilot then made a right, 270° turn and flew toward Steerpoint 2. He then made a left turn around a grouping of five lights and headed toward Steerpoint 3, while climbing to 19,000’ MSL. The pilots made a left turn at the third steer point, and headed back toward the Tonopah runway. The duration of each test condition was approximately seven minutes.

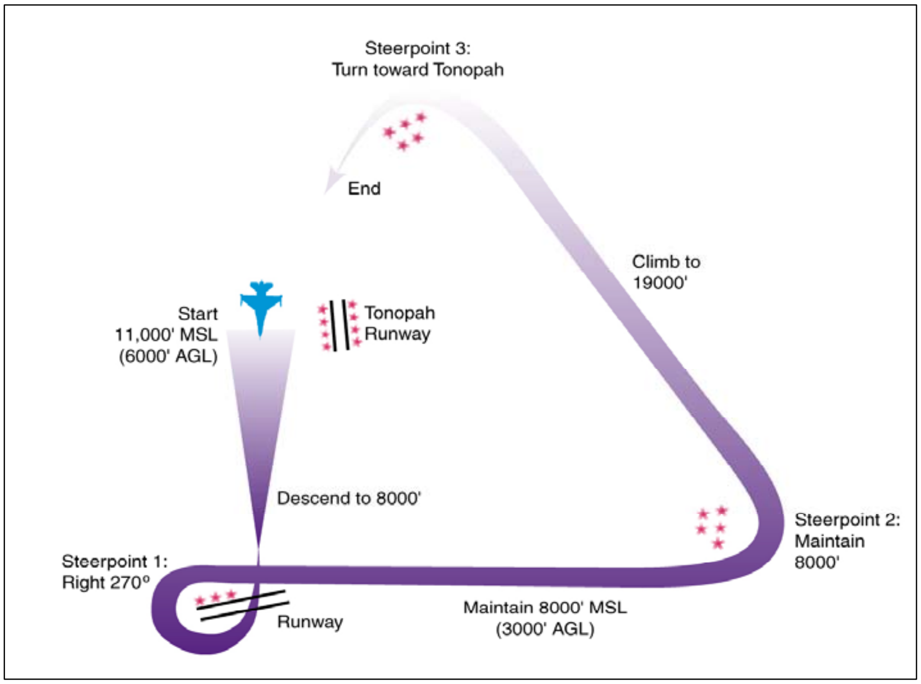

Figure 10. Route for NVTS / Legacy integration flight trials

After completion of each test condition, pilots rated the degree of difference they noted between the NVTS HMD scene and the OTW scene, for several HMD scene characteristics. The rating scale used consisted of the following categories: 0 = No Disparity, 1 = Slight Disparity, 2 = Moderate Disparity, 3 = Extreme Disparity. Pilots rated the degree to which any difference noted affected their flight performance. Specific comments regarding the disparities noted between the NVTS HMD and the OTW scenes were recorded.

Results

Pilots rated the degree of mismatch they noticed between the NVTS HMD and OTW databases for certain scene attributes at the completion of each test condition. The average ratings for each attribute are listed in Table 4 as a function of test condition.

A rating of "0" indicates that pilots noticed no disparity between the NVTS HMD view and their expectations of the OTW scene for a particular attribute. A "No Disparity" rating in all cells would indicate that the pilots perceived all the attributes of the unaided OTW scene as accurate, given the HMD scene conditions. A rating of "1" denotes they noticed a slight degree of disparity between the two scenes. Inspection of Table 4 reveals that most of the ratings are either "none" or "slight."

Pilots rated the degree of mismatch between the NVTS HMD and the SGI OTW (shaded columns in Table 4) as "No Disparity" to "Slight" for all scene attributes except "Number of stars." The degree-of-mismatch ratings between the NVTS HMD and the SE 2000+ OTW for the "Number of stars," "Appearance of moon," "Terrain features," "Terrain brightness," and "Cultural lights" were rated "Slight" to "Moderate" for at least one illumination condition. The ratings for these four attributes are described in the following paragraphs.

Table 4. Average "degree-of-mismatch" rating between NVTS HMD and OTW scenes as a function of test condition.

OTW Test condition → / Scene Attributes ↓	SGI High Illum.	SE 2000+ High Illum.	SGI Low Illum.	SE 2000+ Low Illum.
Number of stars	0	1.5*	2*	1.33*
Position of stars	0	0.33	0.5	0.33
Position of moon	0.25	0.25	NA	NA
Appearance of moon	0.25	1.25	NA	NA
Terrain brightness	0	1	0.25	1.25
Cultural lights	1	0.67	0.25	1
Buildings	0	0	0	0
Roads	0	0	0	0
Terrain features	0	1	0	0
Horizon position	0	0.25	0	0
Pitch change response	0	0	0	0
Roll response	0	0	0	0

(0 = No Disparity, 1 = Slight Disparity, 2 = Moderate Disparity, 3 = Extreme Disparity)

* Due to improper modeling of the stars at the time of the evaluation, visibility of the stars was severely limited.

Number of stars

The mismatch ratings noted for "Number of stars" is attributable to the limited quantity (3,000) and low visibility of the stars in the NVTS HMD. Reductions in moon illumination-level in the NVTS HMD scene resulted in an unintentional decrease in the brightness of the stars (due to improper modeling). Two pilots also commented that the stars were too bright and too large in the SE 2000+ OTW scene.

Appearance of moon

During the high illumination conditions, the moon in the NVTS HMD and OTW scenes appeared as a half disc, while the moon in the SE 2000+ OTW display had a smaller, irregular appearance. The degree of this mismatch (in the SE 2000+) was rated as slight by two pilots, severe by one pilot, and no difference by one pilot (average rating = 1.25). One pilot commented that this difference in appearance of the moon had a "Slight" adverse effect on his performance.

Terrain brightness and features

Three of the four pilots noted a mismatch in terrain brightness between the NVTS HMD and the SE 2000+ OTW scene (average rating = 1.25). These pilots commented that terrain brightness in the SE 2000+ OTW scene was too dim during both illumination conditions. The SE 2000+ OTW terrain brightness level during the high illumination condition probably influenced the "Slight" mismatch rating for "Terrain features." Three pilots commented that the terrain was too dim to discern the terrain features. One pilot commented that he could not see the horizon at low illumination in the SE 2000+. Another pilot commented that the scene detail in the SE 2000+ lacked texture. No disparity in terrain brightness was noted for the NVTS HMD and SGI OTW display condition.

Cultural lighting
Pilots noted a “slight” disparity in cultural lighting between the NVTS HMD and the SE 2000+ scene during the low illumination condition. One pilot noted that more cultural lights in the SE 2000+ OTW would be useful toward maintaining situational awareness (SA). This pilot also noted that the scarcity of cultural lights and ground illumination in the SE 2000+ had a “moderate” negative effect on performance during the low illumination condition.

Performance Impact
Pilots also rated the extent to which any disparity between the NVTS HMD and OTW scene adversely affected flight performance. The effect on flight performance was rated as “none” in nearly all cases, except for the instances noted in the previous paragraphs.

CONCLUSIONS AND RECOMMENDATIONS

Subjective Flight Evaluation

The results of the flight evaluation demonstrated that when pilots did note disparities between the HMD and the OTW, these mismatches were rated as only “slight” except for the “number of stars” which was affected by improper modeling of the stars at the time of the evaluation. These findings were most likely due to the non-demanding flight task, the lack of large disparities between databases, and efforts to control the scene appearance for each illumination condition.

The pilots flew at altitudes of 3,000 – 6,000 ft AGL and did not point out differences in terrain elevation between the HMD and OTW scenes. This is most likely because the majority of the terrain elevation differences between databases were less than 100 ft. Terrain elevation variations between different databases are likely to be noticeable and more critical for flight tasks such as ordnance delivery, low-level routes, and approaches to landing. When the simulator mission involves ordnance delivery or low-level flying (where NVGs are essential for critical visual information), the system should be configured such that the host receives database-specific information from the NVTS IG. When the mission involves approaches (when NVGs are not used), the host should receive this information from the OTW IG. The visual scene presented to the pilot must be appropriate for the relevant task(s). If the correct visual information is not presented, negative training may occur. For example, if the host receives information from the OTW IG during ordnance delivery, the weapons impact point (calculated by the host) will correspond to the OTW target location and elevation and the pilot will view and react to the target impact point based on the NVTS (NVG) visual scene. During the next pass the pilot may try to compensate for what he perceives as inaccuracies on his part during the first pass. The missed distance may actually stem more from the differences in terrain elevation between databases than from his performance. On the other hand, during a full-mission simulation with ordnance delivery, takeoffs, and landings, it may be necessary to switch between IGs providing the database specific information at appropriate times during the mission.

The following recommendations for Legacy/NVTS integration were derived from this flight evaluation:

1. Adjust OTW display brightness and contrast levels to approximate “real-world” luminance levels. Account for sky glow, peripheral cultural light sources, etc.
2. Match moon phase and position in OTW and NVTS scenes.
3. Include stars in NVTS and OTW scenes. Model the relative difference between the number of visible stars in each scene, to the extent possible, without degrading performance. (The NVTS should have a much greater number of stars than the OTW scene.)
4. Force cultural lighting sources to identical locations in OTW and NVTS databases.
5. Set host to listen to either NVTS or OTW IG; depending on flight tasks.

Engineering/Integration Contingencies

The following paragraphs describe the various integration issues that may be encountered when integrating a different legacy system with NVTS.

Host to NVTS communications
There must be a high-speed data connection from the NVTS IG to the host either via Ethernet, shared memory, or some other means. If Ethernet is not an option, additional hardware and software will be necessary.

Database Correlation
The two databases tested during this evaluation matched up fairly well. If the mismatch between the two databases is significant, decisions must be made as to which IG the host will listen to and the following options must be considered: (1) Turn off the OTW IG. This option is not desirable because most NVG experienced pilots say they want the unaided night scene in addition to the NVG scene. This option should only be considered in cases of severe mismatch. (2) Modify the databases to correlate in critical areas such as runways, target areas, mountain passes or any area deemed necessary to enable quality training. This may be quite costly in most cases or even impossible when the capability to change the legacy database no longer exists.

HUD Conversion
If the legacy system has a HUD, then the HUD video must be provided to the digitizer in RS-170 format. When RS-170 format HUD video is not available, then the existing HUD video must be converted either by scan conversion or by stroke-to-raster conversion, depending on the type of HUD in the legacy system. During this evaluation, RS-170 video of the HUD display was provided via scan conversion from a 1024 x 768 noninterlaced video source.

Latency Differences
During this evaluation latency differences were relatively small and not noted by the subjects. If latency differences are significant, then use NVTS as a stand-alone display system for the legacy cockpit.

Cockpit Model
The aircraft-specific cockpit model should be created using a standard COTS 3-D modeling package. Ideally, a photorealistic material map should be applied to the model to simulate the detail within the cockpit. Cockpit lights and the canopy should be included in the model since they degrade the NVG scene in the real world. Canopy glare should be modeled in the runtime to effectively simulate NVGs in a dynamic environment. The model needs to be easily manipulated within the runtime environment to align it to the augmented reality (i.e., cockpit). The runtime should have a mode enabling real-time 6-degree of freedom (DOF) placement control of the model via keyboard input, mouse (e.g., Labtec's Spaceball®), or some other method.

Head-Tracker Options
The Polhemus Fastrak® magnetic head tracker was employed with this Legacy system. A different type of head tracker may be required to accurately track head position in other simulator environments. For example, the metal in some cockpits will distort the magnetic fields produced by a magnetic head tracker, causing inaccurate tracking head position. This will alter the user's view of the simulation. Table 5 points out the major characteristics of one example for each type of headtracker. Figure 11 presents options for employing the various types of head trackers, based on the simulation environment.

Table 5. Examples of various head-tracker types

Head Tracker type ⇒	Magnetic (DC Field)	Inertial	Magnetic (AC Field)	Optical (Laser)	Optical (IR Array)
Example ⇒	*Ascension Flock of Birds®*	*InterSense IS-300Pro®*	*Polhemus FASTRAK®*	*Ascension laserBIRD®*	*3rd Tech HiBall Tracker®*
Update Rate	Up to 144 Hz	Up to 500 Hz	Up to 120 Hz	240 Hz	Up to 2000 Hz
Latency	8 ms – 12 ms	2 ms	4 ms	5.7 ms (typical) 7 ms max	< 1 ms
Sensor Weight	17.8 g	60 g	9 g	40 g	170 g
Sensor Dimensions (LxWxH)	2.54 cm x 2.54 cm	2.7 cm x 3.4 cm x 3.048 mm	2.286 cm x 2.79 cm x 1.52 cm	7.6 cm x 7.6 cm x 0.80 cm	7.3 cm (tall) x 5.4 cm (dia.)
Transmitter Dimensions (LxWxH)	9.6 cm cube	N/A	5.8 x 5.6 x 5.6cm	27.8 x 8.1 x 4.0 cm	Limited
Prediction (Internal)	No	Yes (up to 50 ms)	No	No	No
Interface	RS-232C w/ selectable baud rates to 115,200K	RS-232C w/ selectable baud rates to 115,200K	RS-232 w/ selectable baud rates to 115,200K (optional RS-422)	RS-232 or USB	Ethernet
Sensor Position Accuracy	1.8 mm RMS	N/A	7.6 mm RMS	1.0 mm RMS	0.5 mm RMS
Sensor Position Static Resolution	0.5 mm @ 30.5 cm	N/A	0.6 mm @ 30.5 cm	0.1 mm @ 1 m	0.2 mm (over entire range)
Sensor Angle Range	All orientations	All orientations	All orientations	±85° Az & El, ±180° Roll or ±180 Az, ± 85 El & Roll	±180° Az 0°–90° El
Sensor Angle Accuracy	0.5° RMS	1.0° RMS	.15° RMS	0.5° RMS	0.03° RMS
Sensor Angle Static Resolution	0.1° @ 30.5 cm	0.02°	0.025°	0.05°	0.03°

The various head tracker types are each suited for particular simulator environments, as seen in Figure 11. Optical head trackers are preferred when no instruments, switches, or visual displays are above the operator's head.[1] 3rd Tech's optical HiBall Tracker® requires typical "drop ceiling" area for transmitter array installation.[2] This optical (IR array) head tracker may work well where crewmembers must move about the cockpit or in a classroom workstation environment. Ascension's laserBIRD® may be used when there is at least 90 cm between the head and the transmitter mounting surface/stand.[3] The laserBIRD works well in a less than 360° field of regard (FOR) visual display. The transmitter will block a small area in a 360° FOV visual display.[4]

Magnetic (AC and DC) and inertial trackers may be employed when operating space is limited.[5] Magnetic trackers are preferred over inertial trackers because magnetic trackers provide orientation data (heading, pitch, and roll) and X, Y, Z position data. Inertial trackers only provide orientation data, unless additional hardware is employed. However, any magnetically conductive material in the area of operation will distort the output from both AC and DC magnetic trackers. These distortion effects may be reduced by incorporating a magnetic field map into the tracker software. DC head trackers are preferred (over AC) in environments where a high metal content is in the area of operation.[6] Inertial head trackers work in the most constrained environments. [7] They do not require a transmitter and are only somewhat affected by metal and RF fields.

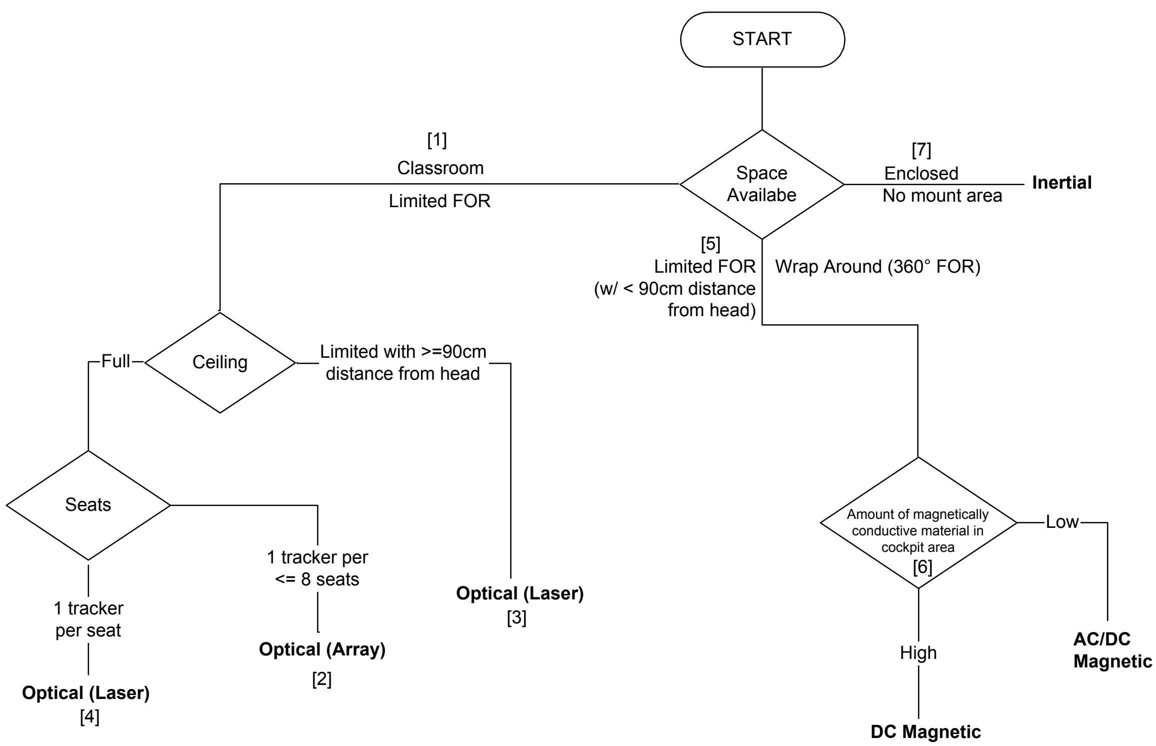

Figure 11. Head-tracker options based on environment